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A review on the pattern of electricity generation and emission in Indonesia from 1987 to 2009

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ABSTRACT

The level of energy demand plays a fundamental role in today's society. It is a vital input in supporting the physical and social development of a country, as well as national economic growth. Looking at the energy demand scenario in present time, the global energy consumption is likely to grow faster than the population growth across the world. Like any other energy sectors, electricity demand has significantly increased in Indonesia over the past years. Currently, there are six types of power plants in the country. The main sources of electrical energy are generated using the gas turbines, steam turbines, combined cycles, geothermal, diesel engine and hydro-powers. Most of Indonesia's power plants are using fossil fuel for electricity generation. Substantial growth in domestic energy demand, however, would be a major challenge for Indonesia's energy supply sector in the future. Over the past decade, thermal power plants generated about 86.69% of electricity and about 13.31% was generated by renewable energy such as hydro-power and geothermal in 2009. The purpose of this study is to chronicle and show a clear view of 23 years trend of Indonesia's electricity generation industry. Furthermore, the capacity of power generation installed and electricity generation from 1987 to 2009 has been gathered for this study. The total pollutant emissions and emission per unit electricity generation for each type of power plants have been also calculated using emission factors. Also, the pattern of electricity generation and emission has been presented. The results show that the implementation and contribution of combined cycle power plants should be increased together with renewable energy and natural gas which are recommended to reduce greenhouse gas emission.

Contents

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Nomenclature

CV	calorific value (kcal/m^3, kcal/l, kcal/kg)
EF	emission factor in power plant (kg/M m^3)
EG	electricity generation in power plants (GWh)
EM	power plant emission (ton)
EP	emission per unit electricity generation (kg/GWh)
FC	power plant fuel consumption (Mm^3)
FE	share of fuel consumption (%)
k, C	constant values
NC	power plant nominal capacity (%)
NP	share of nominal capacity (%)
P	population
PC	per capita electricity consumption (kWh)
PE	share of electricity generation (%)
PF	share of thermal energy (%)
PN	per capita nominal capacity (W)

Subscripts

f	fuel type consumed in power plant
i	in the year i
j	range of selected years

Superscripts

n	power plant type
p	emission type

1. Introduction

1.1. Energy supply and demand in Indonesia

Indonesia is an ASEAN country stretches from 6°08′N latitude to 11°15′S latitude, and from 94°45′E to 141°05′E longitude [1]. The country covers approximately about 1,922,570.00 km^2 of land area with population number reaches up to 237 million people as of 2010 [2]. Indonesia has an abundance of natural resources suitable for electricity generation including coal, natural gas, oil, geothermal and hydropower. Most of Indonesia's energy supplies (about 75%) come from non-renewable energy [2]. However, despite using oil as a fuel for power generation, the country has considered to use coal and natural gas as substitutes for liquid based fuel due to declining production in recent years. Although Indonesia has large reserve of natural gas (approximately 107 trillion cubic feet) and most of it being exported, the effort of shifting natural gas towards domestic use is being hindered by poor natural gas transmission and network distribution [3]. The country also produces 256 MMst (million short tons) of coal in 2009, in which 198 MMst or 77% out of the total was exported, while the remaining 58 MMst of coals (relatively small compared to its production) were mainly used for electricity generation or utilized in industrial sectors [2]. Some regulations have been established to increase the share of natural gas and coal in the future energy mix especially for electricity generation purposes. According to final energy demand in 2009, industrial sector was the largest consumer of energy with 41% of total energy consumption. The shares of final energy consumption for other sectors are transportation 37% and 22% for residential and commercial sector [2]. Some related work on energy supply and demand in Indonesia discussed by Refs. [4–8].

1.2. Electricity generation in Indonesia

The electricity demand in Indonesia has increased tremendously in 23 years of time (1987–2009). In 2009, Indonesia's electricity production reaches 155,334 GWh, which is 620% more than the production of electricity in 1987 (21,559.29 GWh) [2,10]. Nominal capacity of Indonesian power plants is 31,375.04 MW, in which 83% of the total nominal capacity or 26,041.28 MW was contributed by the National Electricity Company (PLN). The rest of the energy supplied was contributed by Independent Power Plant (IPP) that reaches up to 4392.50 MW of energy or 14%, and finally 920 MW (or 3%) of energy was contributed by PPU (Private Power Utility) [11]. Some works related to electricity generation in Indonesia are discussed by Refs. [12–19].

Currently, the national electrification ratio is 66% and village electrification ratio is 93%. This is due to electricity demand growth that are not able being pursued by the growth of power supply [11]. At present, most of Indonesian power plants are using non-renewable sources such as natural gas, fuel oil, coal and diesel to generate electricity. These power plants operate using steam turbine, combined cycle, gas turbine and diesel engine. Some types of power generation in Indonesia are discussed below.

1.2.1. Steam turbine power plants

Steam power plants rely on high pressure steam to generate electrical energy. Steam power plant uses a variety of fuels, especially coal while fuel oil used for startup. Currently steam power plant in the country has 12,309.00 MW nominal capacity equivalents to 39.23% of total nominal capacities and produce 48.19% of the total electricity generation of the country in 2009 [2]. The conventional steam power plants in Indonesia have thermal efficiency which vary from 30% to 35% [20].

1.2.2. Combined cycle power plants

Combined cycle power plant is a type of power plant that uses a combination between the Brayton cycles of gas turbine with Rankine cycle of HRSG (Heat Recovery Steam Generator) which is

channeled directly into the steam turbine, where the exhaust gas from gas turbine is used as working fluid to produce steam in HRSG [21]. This type of power plant has 8076.97 MW of nominal capacity; equals to 25.74% of total nominal capacities and produces 25.86% of the total electricity generation in the country in 2009 [2]. Commonly, commercial combine cycle power plants available in the market have thermal efficiency in range 50–55% depend on lower heating value [22].

1.2.3. Gas turbine power plants

This type of plant uses Brayton cycle with natural gas and diesel as fuels to produce electricity. Gas turbine power plants are sometimes used as emergency power generator or in situations where there is an extra demand for energy that primary power plants may not be able to cope at peak hours. The existing capacity of this power plant type is 3365.59 MW of energy; equals to 10.73% of total nominal capacities and produces 5.58% of the total electricity generation in 2009 [2]. Gas turbine power plants in Indonesia have thermal efficiency between 25% and 30% [23].

1.2.4. Diesel power plants

A diesel engine coupled with a generator is used to convert mechanical energy to electrical energy. This kind of power plants is usually used in hospitals as backup for power source and also in industries that require a constant, uninterrupted power supply. The current installed capacity of this power plant in Indonesian power distribution network is 2980.63 MW or equivalents to 9.50% of total nominal capacities and produces 7.05% of the total electricity generation in 2009 [2]. This type of power plant in Indonesia has thermal efficiency around 30% [23].

1.2.5. Renewable energy power plants

Renewable energy is the energy derived from natural processes that do not involve exhaustible resources such as fossil fuels and uranium. Indonesia has an abundance of potential renewable energy resources such as hydro-power, geothermal, wind energy, solar energy and biomass. Today's global trend of renewable energy sources represents only a small fraction of the total energy generated. Despite the high growth rates, renewable energy is still not fully utilized yet. This is due to expensive technologies, high investment costs and low awareness that generally plague most of the developing countries around the world today. Indonesia is currently using renewable energy sources such as hydro and geothermal for electricity generation. Biomass sector particularly for electricity generation has also been recently exploited due to the abundance of oil palm trees in the country. Some works on renewable energy power generation in Indonesia are discussed in Refs. [24–31].

a. *Hydro-power plants* – Hydro-power is a type of renewable energy technology that is commercially viable on large scale in Indonesia. It is not only producing zero emissions, but also produce large amount of sustainable electricity, although the startup cost is expensive. The country has a huge amount of hydropower resources. However, the share of hydropower energy only 11.22% of nominal capacity (about 3500 MW) and 7.33% of electricity generation in 2009. [2].
b. *Wind turbines* – Wind energy can be converted into useful energy such as electricity. Utilization of wind power as an energy source in the country is being seen as good potentials for electricity production, especially in coastal areas where wind is abundant. With the wind speeds between 2 and 6 ms^{-1}, the suitable wind power generators to develop in Indonesia are small (10 kW) to medium scale power generations (10–100 kW) [32]. The nominal capacity of this type of power plant is 1.06 MW of total electricity generation in 2009 [2]. The potential implementation of wind turbine in Indonesia and other developing countries are presented by Refs. [33–37].
c. *Other source of energies* – At present, there are a lot of other energy related projects in Indonesia. The country is currently launching and developing new energy segments that have never been used before in Indonesia which are all under feasibility study or still under development stages. Some related works on solar thermal, solar photovoltaic, biomass, biogas, hydrogen, sea waves and fuel cells for power and energy generation are presented by Refs. [38–52].

Table 1
Fuel types consumption in all of Indonesian thermal power plants.

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Coal	x	–	–	–
Natural gas	x	x	x	–
Fuel oil	x	–	–	–
Diesel	–	x	x	x

(x), fuel is consumed in power plant; (–), fuel is not consumed in power plant.

1.3. Power plant fuel consumption

Economic, political and technical parameters influence the type of fuel selected for power plants in a country. Technical parameters that needed to be considered as a main reason for the development of a power plant include the type of fuel available, cost of fuels, geographical location of the power plant, environmental concerns and medium to long term policies of the energy sector of the country. Most of Indonesian power generation comes from thermal power plants that consume fossil fuels such as coal, natural gas, diesel and petroleum fuel. Coal, natural gas and fuel oil are widely used for steam turbines; whereas gas turbine and combined cycles power plants utilize natural gas and diesel as fuels. Diesel engine utilize diesel as a fuel without any additional fuel. The types of fuel consumed in Indonesian power plants are summarized and presented in Table 1.

1.4. Energy policy in Indonesia

In recent years, several actions have been taken in order to increase the efficiency and capacity of power generation. Currently, Indonesian government policy is to accelerate the energy diversification for electricity generation from oil to the other resources, mainly to promote natural gas and coal utilization in the power generation sector. Government also try to increase the share of geothermal and combined cycle power plant which have better thermal efficiency than any other type of power plant. By using combined cycle power plant, it resulted in higher efficiency of the unit, and less consumption of fuels and subsequently lower emission will be released. Some of discussions on Indonesia's energy policy are presented by Refs. [53–57].

1.5. Power plant emission

In general, thermal power plants operated using fossil fuels produce a huge amount of air pollutants. The major pollutants that have been considered in this study are carbon monoxide (CO), sulfur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxide (NO_X).To estimate the total emission due to electricity generation in the country, the amount and type of fuel used in all of the power plants should be identified. A complete data on the amount of the emission per unit electricity generation in each type of thermal power plants is necessary to select the best type of power plant with regards to air pollutants and assessment of possible emission in the future. The methods of calculating emission from power generation based on fuel type can be found in Refs. [58–68].

Table 2
Nominal capacity (MW) for various type of Indonesian power plant from 1987 to 2009.

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power	Total
1987	2816.95	1116.68	–	140.00	1651.86	1512.06	7237.55
1988	3416.95	1233.68	–	140.00	1769.02	1969.57	8529.22
1989	3946.95	1233.68	–	140.00	1794.89	1972.95	9088.47
1990	3940.60	1230.09	–	140.00	1869.60	2928.65	10,108.94
1991	3940.60	1213.86	–	140.00	1945.96	3091.54	10,331.96
1992	3940.60	1222.76	1312.05	140.00	2059.56	3299.98	11,974.95
1993	4690.60	94.61	3411.31	195.00	2118.74	3355.38	14,745.64
1994	4755.60	1168.51	3942.11	305.00	2164.12	3356.43	15,691.77
1995	4821.00	1020.00	4413.00	308.00	2228.00	3363.99	16,153.99
1996	5020.60	1093.31	5203.31	308.75	2448.84	3366.01	17,440.82
1997	6770.60	1431.12	5738.89	527.50	2416.39	3620.38	20,504.88
1998	7970.60	1407.41	6845.97	525.00	2535.02	4190.64	23,474.64
1999	9170.00	1576.11	6566.70	525.00	2649.94	4196.13	24,683.88
2000	9170.00	1263.37	7148.22	705.00	2549.85	4199.28	25,035.72
2001	9300.00	1284.72	7148.22	705.00	2585.12	4289.80	25,312.86
2002	9300.00	1284.72	7148.22	785.00	2589.12	4339.21	25,446.27
2003	9300.00	1284.72	7148.22	807.00	2670.62	4351.77	25,562.33
2004	10,865.00	1541.57	6845.97	852.00	3276.93	4383.48	27,764.95
2005	10,865.00	2783.63	6655.97	855.50	3325.62	4405.00	28,890.72
2006	11,670.00	3396.22	7318.39	820.00	3001.49	3532.47	29,738.57
2007	12,014.00	3452.63	7318.27	932.50	3069.77	3512.90	30,300.07
2008	12,309.00	3165.69	7738.11	1002.50	3134.40	3515.89	30,865.59
2009	12,309.00	3365.59	8076.97	1122.50	2980.63	3520.35	31,375.04

Table 3
Electricity generation (GWh) for various types of power plant from 1987 to 2009.

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power	Total
1987	12,221.83	1374.67	–	719,39	2785.99	4457.41	21,559.29
1988	14,218.38	1581.98	–	1011.96	2900.87	5226.86	24,940.05
1989	16,468.19	1454.41	–	1006.87	3157.04	6629.66	28,716.17
1990	19,713.78	2174.96	–	1125.42	3609.13	6492.44	33,115.73
1991	23,242.27	2640.01	–	1049.46	3761.72	7409.17	38,102.63
1992	22,888.69	2688.91	–	1083.74	3977.53	9645.48	40,284.35
1993	21,983.60	1572.85	1775.27	1089.97	4331.26	8891.08	39,644.03
1994	21,585.71	1013.21	8830.35	1601.76	4601.05	7982.94	45,615.02
1995	22,738.92	1219.07	14,228.36	2210.03	4930.51	8293.14	53,620.03
1996	25,492.24	1299.06	14,875.25	2340.37	5414.27	8824.37	58,245.56
1997	30,109.79	1731.49	23,043.91	2725.88	6303.03	5865.62	69,779.72
1998	30,517.37	1395.51	24,980.78	3284.00	5331.85	10,363.50	75,873.01
1999	34,004.54	1555.04	27,045.52	3938.23	5371.46	10,379.78	82,294.57
2000	43,661.00	1252.00	27,079.00	4869.00	6449.00	10,016.00	93,326.00
2001	47,767.00	1459.00	28,139.00	6031.00	6608.00	11,655.00	101,659.00
2002	52,659.00	2229.00	29,728.00	6238.00	7430.00	9933.00	108,217.00
2003	62,370.00	2486.00	29,920.00	6294.00	8260.00	9099.00	118,429.00
2004	59,083.00	3179.00	32,647.00	6656.00	8924.00	9674.00	120,163.00
2005	60,832.00	6039.00	34,211.00	6604.00	8959.00	10,725.00	127,370.00
2006	68,066.00	5031.00	34,521.00	6658.00	9209.00	9623.00	133,108.00
2007	74,184.00	5148.00	35,634.00	7021.00	9166.00	11,286.00	142,439.00
2008	72,570.00	5621.00	40,663.00	8309.00	10,746.00	11,528.00	149,437.00
2009	74,861.00	8674.00	40,165.00	9295.00	10,958.00	11,381.00	155,334.00

2. Survey data

The data used for this study are based on electricity generation, fossil fuel used and the population of Indonesia in selected years. These data are collected and extracted from Refs. [2,9,10,69,70,71] and shown in Tables 2–6. Due to the lack of time series data, therefore some of the data were interpolated based on available data.

Table 4
Population of Indonesian for selected years between 1971 and 2010.

Year	Population
1971	119,208,229
1980	147,490,298
1990	179,378,946
1995	194,754,808
2000	206,264,595
2010	237,641,326

The emission factors for all types of fuel were mostly obtained from Refs. [72,73] and given in Tables 7 and 8.

The characteristics of fuel used in Indonesian power plant are important to assess the contribution of each fuel emission. Calorific value is essentials to calculate thermal energy available for types of fuel. Fuel oil calorific value is 9370 kcal/L, diesel calorific value is 9070 kcal/L, natural gas calorific value is 8904 kcal/m^3 and coal calorific value is between 4200 kcal/kg and 5100 kcal/kg [74]. To calculate the amount of SO_2, the sulfur content for diesel assumed to be 5000 ppm (equivalent to 0.5%) and 3% for fuel oil.

3. Methodology

3.1. Method of data estimation

There are several methods for estimating data; the one that widely used is polynomial curve fitting. This method tries to describe the relationship between a variable X as the function of

Table 5
Total fossil fuel consumption (Mm^3 and kton) for power plants from 1987 to 1996.

Year	Coal (kton)	Fuel oil (Mm^3)	Diesel (Mm^3)	Natural gas (Mm^3)
1987	2084.15	1.99659	1.32976	195.72
1988	2746.01	2.10132	1.34009	281.22
1989	3970.56	1.89052	1.27457	334.36
1990	4421.87	2.58559	1.62165	365.90
1991	5000.55	3.10952	1.90009	365.53
1992	5005.16	3.25203	2.40901	420.16
1993	4789.28	1.04368	3.13030	1346.70
1994	5530.07	1.86564	1.92790	4547.95
1995	5593.40	1.15759	1.82584	6226.91
1996	7966.66	1.11101	2.23629	7051.17

Table 6
Composition of fuel consumption (kton and Mm^3) in Indonesian power plants from 1997 to 2009.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1997*	Coal (kton)	9961.959	–	–	–	9961.959
	Natural gas	1052.480	25.00660	5382.491	–	6459.978
	Fuel oil	1.554361	–	–	–	1.554361
	Diesel	–	0.440381	0.977533	1.633801	3.051715
1998*	Coal (kton)	10643.49	–	–	–	10643.49
	Natural gas	1023.834	24.32597	5235.991	–	6284.150
	Fuel oil	1.395729	–	–	–	1.395729
	Diesel	–	0.395437	0.877770	1.467062	2.740268
1999*	Coal (kton)	11414.10	–	–	–	11414.10
	Natural gas	1090.952	25.92068	5579.240	–	6696.113
	Fuel oil	1.587124	–	–	–	1.587124
	Diesel	–	0.449663	0.998138	1.668239	3.116040
2000	Coal (kton)	13135.58	–	–	–	13135.58
	Natural gas	1055.109	25.07012	5395.926	–	6476.105
	Fuel oil	1.695268	–	–	–	1.695268
	Diesel	–	0.480302	1.066149	1.781910	3.328361
2001	Coal (kton)	14027.71	–	–	–	14027.71
	Natural gas	997.2578	79.02294	5218.227	–	6294.508
	Fuel oil	1.789627	–	–	–	1.789627
	Diesel	–	0.554638	1.244474	1.810349	3.609461
2002*	Coal (kton)	14054.34	–	–	–	14054.34
	Natural gas	690.5483	130.2946	4934.284	–	5755.127
	Fuel oil	2.166224	–	–	–	2.166224
	Diesel	–	0.731218	1.716281	1.892562	4.340060
2003	Coal (kton)	15260.30	–	–	–	15260.30
	Natural gas	383.9110	181.5654	4650.340	–	5215.816
	Fuel oil	2.542822	–	–	–	2.542822
	Diesel	–	0.907797	2.188088	1.974774	5.070659
2004	Coal (kton)	15412.74	–	–	–	15412.74
	Natural gas	395.4634	359.9321	4237.747	–	4993.143
	Fuel oil	2.642689	–	–	–	2.642689
	Diesel	–	0.843656	3.047393	1.990679	5.881729
2005	Coal (kton)	16900.97	–	–	–	16900.97
	Natural gas	260.2499	438.4709	3349.596	–	4048.316
	Fuel oil	2.226523	–	–	–	2.226523
	Diesel	–	1.750112	3.843320	2.067968	7.661400
2006	Coal (kton)	19084.44	–	–	–	19084.44
	Natural gas	275.0336	579.3432	3607.500	–	4461.877
	Fuel oil	2.359120	–	–	–	2.359120
	Diesel	–	1.582632	3.904159	1.847869	7.334660
2007	Coal (kton)	21466.35	–	–	–	21466.35
	Natural gas	558.9810	543.1262	3912.753	–	5014.860
	Fuel oil	2.702131	–	–	–	2.702131
	Diesel	–	1.582632	3.904159	2.292993	7.779784
2008	Coal (kton)	20999.52	–	–	–	20999.52
	Natural gas	259.5232	556.0220	4257.539	–	5073.084
	Fuel oil	2.827173	–	–	–	2.827173
	Diesel	–	1.705135	4.273991	2.514191	8.493316
2009	Coal (kton)	21604.46	–	–	–	21604.46
	Natural gas	242.3193	2022.705	5231.956	–	7496.981
	Fuel oil	2.588586	–	–	–	2.588586
	Diesel	–	1.115367	2.950344	2.754607	6.820318

Note. Natural gas, fuel oil and Diesel data are measured in Mm^3.
* The data are adopted and analyzed by the author based on available data.

Table 7
Emission factor (kg/KWh) used for estimating emission in power plants.

Fuels	Emission (kg/kWh)			
	CO_2	NO_X	SO_2	CO
Coal	1.18	0.0052	0.0139	0.0002
Natural gas	0.53	0.0009	0.0005	0.0005
Fuel oil	0.85	0.0025	0.0164	0.0002
Gas	0.85	0.0025	0.0164	0.0002

available data and a response Y that seeks to find a smooth curve for the best fit of the data. Mathematically, a polynomial of order k in X can be expressed in the following equation form [75]:

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \quad (1)$$

3.2. Electricity generation statistics

3.2.1. Per capita nominal capacity

The per capita nominal capacity for each year is the total nominal capacities divided by the population in that particular year. The per capita nominal capacity in the year i can be calculated by the following equation:

$$PN_i = \frac{NC_i}{P_i} \quad (2)$$

3.2.2. Per capita electricity consumption

The per capita electricity consumption in the year i is electricity production divided by population in particular year, which can be calculated by the following equation:

$$PC_i = \frac{EG_i}{P_i} \quad (3)$$

3.2.3. Percentage of electricity generation and nominal capacity

To understand the changes in pattern of electricity generation and nominal capacity, the share of each type of power plants should be identified. Share of electricity generation and share of nominal capacity can be calculated by the following equations:

$$PE_i^n = \frac{EG_i^n}{EG_i} \times 100 \quad (4)$$

$$NP_i^n = \frac{NC_i^n}{NC_i} \times 100 \quad (5)$$

3.3. Emission

Due to the lack of any time series emissions measurements or frequent stack measurements, emission factors have been used to calculate an emissions. The data of CO_2, SO_2, NO_X and CO emissions from fossil fuel for a unit of electricity generation are determined. The emission data are based on emission factors for each fuel type and the types of power plants.

As mentioned early, all power plants (except diesel engines) use more than one type of fossil fuel. This means that emission factor of a fuel will be different based on the power plant type.

3.3.1. Emission production

Emission production is equal to emission factor multiplied by the amount of fuel consumed. Therefore, the emission p due to use fuel f in power plant type n in year i, can be calculated by the following equation:

$$EM_{if}^{np} = EF_f^{pn} \times FC_{if}^n \quad (6)$$

To assess the impact of each type of fuel in total emission of each power plant, contribution of each fuel in total emission should be calculated by the following equation:

$$FE_{if}^{np} = \frac{EM_{if}^{np}}{\sum_f EM_{if}^{np}} \times 100 \quad (7)$$

The annual emission is the summation of emission for all types of power plants by all types of fuel used. This can be calculated by the following equation:

$$EM_i^p = \sum_n \sum_f EM_{if}^{np} \quad (8)$$

Thermal energy released due to combustion of each type of fuel depends on fuel's calorific values. The share of each type of fuel in total thermal energy consumed in power plants can be calculated by the following equation:

$$PF_{if}^n = \frac{CV_f \times FC_{if}^n}{\sum_f CV_f \times FC_{if}^n} \times 100 \quad (9)$$

3.3.2. Emission per unit electricity generation

The emission per unit electricity generation for each year is a function of annual emission divided by total electricity generated by power plants. This can be calculated by the following equation:

$$EP_i^p = \frac{EM_i^p}{EG_i^t} \quad (10)$$

3.3.3. Emission per unit electricity generation for each type of power plant

The emission per unit electricity generation for each type of power plant is a function of emission factor, fuel consumption in

Table 8
Emission factors (kg/m^3) used for estimating emissions in power plants.

Fuel type	Combustion type	Boiler configuration	CO_2	NO_X	SO_2	CO
Fuel oil	External	Normal	3040	5.63	$18.81 \times S\%$	0.6
Diesel	External	Normal	2660	5.63	$18.81 \times S\%$	0.6
	Internal	Engine	2660	72.37	$18.81 \times S\%$	0.6
		Turbine	2610	14.66	$18.81 \times S\%$	0.6
Natural gas	External	Normal	1.92×10^{-3}	4.48614×10^{-3}	9.61×10^{-6}	1.334×10^{-9}
	Internal	Turbine	1.92×10^{-3}	5.12702×10^{-3}	9.61×10^{-6}	1.334×10^{-9}

$S\%$ indicates percentage of sulfur in the respective fuel, by weight.

each type of power plant and electricity generation from that particular power plant. The emission p per unit electricity generation in a power plant type n in the year i, can be calculated by the following equation:

$$EP_i^{np} = \frac{\sum_f EF_f^{np} \times FC_{if}^n}{EG_i^n} \quad (11)$$

To estimate each type of emission for a unit electricity production in each type of power plants used, only the values related to certain years are applied. The average emission for certain years considered as a selected value, calculated by the following equation:

$$EP^{np} = \frac{EP_i^n + EP_{i+1}^n + \cdots + EP_{i+j-1}^n}{j} \quad (12)$$

4. Results and discussion

4.1. Electricity growth

The nominal capacity and electricity production growth by type of power plant in Indonesia are shown in Figs. 1 and 2. The annual electricity production growth in the country was 9.29% and the annual nominal capacity growth was 6.88%. This is equivalent to the annual growth of 6080.66 GWh of electricity production that needs to create 1097.15 MW of new power generation capacity annually.

4.2. Per capita capacities

The annual population growth is estimated using the data in Table 4 and Eq. (1). The nominal capacity and electricity consumption per person have been calculated using Eqs. (2) and (3) which are based on the statistical data in Tables 2 and 3. From 1987 to 2009, there is no exchange of electricity between Indonesia and its neighboring countries, therefore per capita rate of electricity generation and consumption should remain the same. The results are tabulated in Table 9 and graphically illustrated in Fig. 3.

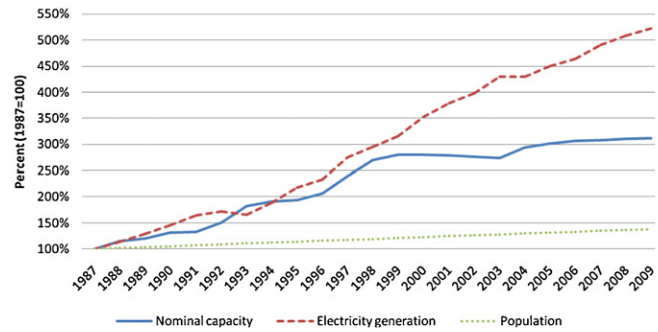

Fig. 3. Per capita nominal capacity and per capita electricity consumption and population growth between 1987 and 2009.

For 23 years, from 1987 to 2009, the average population growth in Indonesia was 1.48%. Whereas, the per capita electricity consumption saw an increase from 127 kWh in 1987 to 663 kWh in 2009 with an average annual growth rate of 7.80%. This increase in energy consumption is due to the economic growth of the country that caused the rate of electricity production was much higher than the population growth.

4.3. Pattern of electricity generation

The pattern of electricity generation and nominal capacity which are based on the type of power plant are calculated using the data in Tables 2 and 3 and Eqs. (4) and (5). The results are tabulated in Tables 10 and 11, and illustrated in Figs. 4 and 5. Fig. 5 shows that fossil fuel dominates most of the share of electrical power generation, much higher than the renewable sources of geothermal and hydro-power energy. This can be said is due to the tendency of using fossil fuel power plants to meet the high demand for electricity. Additionally, the abundance of fossil fuel resources, lack of proper energy management and low investments in renewable energy sources contribute to the high usage of fossil fuel power plants. However, starting from the year 1992, combined cycle power plants were introduced and has since became the second largest contributor of electrical energy amongst the other types of power plants,

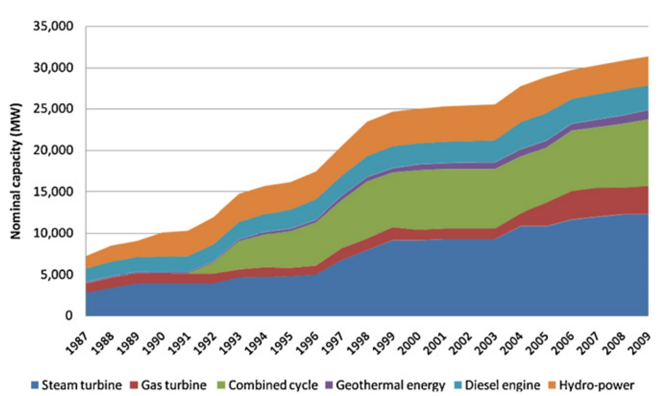

Fig. 1. Nominal capacity (MW) of Indonesian power plants by type of power plant from 1987 to 2009.

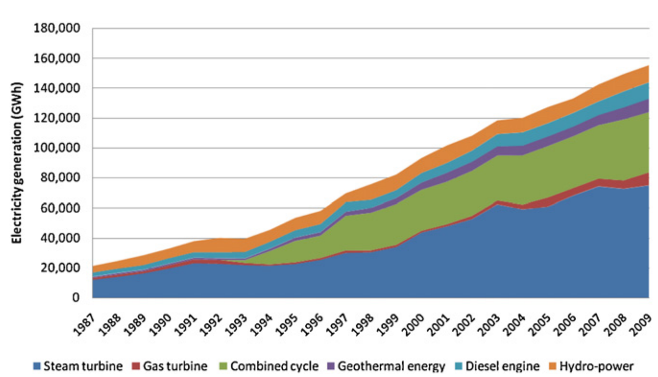

Fig. 2. Electricity generation (GWh) of Indonesian power plants by type of power plant from 1987 to 2009.

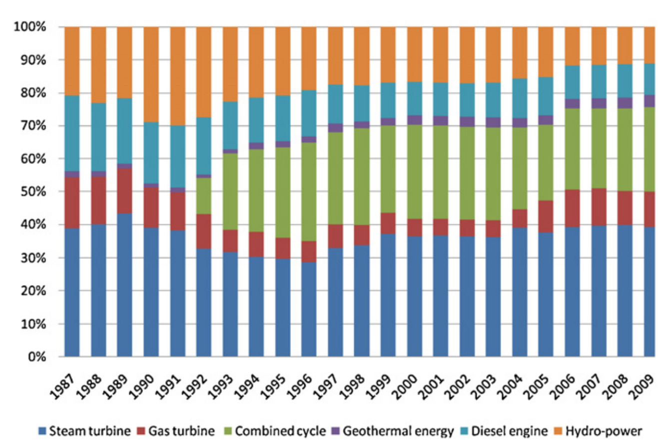

Fig. 4. Pattern of nominal capacity for each type of power plants from 1987 to 2009.

Table 9
Per capita nominal capacity and per capita electricity consumption in Indonesia.

Year	Population	Per capita nominal capacity (Watt)	Per capita electricity consumption (kWh)
1987	169,487,458	43	127
1988	172,539,978	49	145
1989	175,582,143	52	164
1990	179,378,946	56	185
1991	181,635,406	57	210
1992	184,646,504	65	218
1993	187,647,246	79	211
1994	190,637,633	82	239
1995	194,754,808	83	275
1996	196,587,341	89	296
1997	199,546,661	103	350
1998	202,495,626	116	375
1999	205,434,235	120	401
2000	206,264,595	121	452
2001	211,280,387	120	481
2002	214,187,929	119	505
2003	217,085,116	118	546
2004	219,971,947	126	546
2005	222,848,423	130	572
2006	225,714,544	132	590
2007	228,570,308	133	623
2008	231,415,717	133	646
2009	234,250,771	134	663

Table 10
Power plants nominal capacity contribution (%) from 1987 to 2009.

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power
1987	38.92	15.43	0.00	1.93	22.82	20.89
1988	40.06	14.46	0.00	1.64	20.74	23.09
1989	43.43	13.57	0.00	1.54	19.75	21.71
1990	38.98	12.17	0.00	1.38	18.49	28.97
1991	38.14	11.75	0.00	1.36	18.83	29.92
1992	32.91	10.21	10.96	1.17	17.20	27.56
1993	31.81	6.61	23.13	1.32	14.37	22.76
1994	30.31	7.45	25.12	1.94	13.79	21.39
1995	29.84	6.31	27.32	1.91	13.79	20.82
1996	28.79	6.27	29.83	1.77	14.04	19.30
1997	33.02	6.98	27.99	2.57	11.78	17.66
1998	33.95	6.00	29.16	2.24	10.80	17.85
1999	37.15	6.39	26.60	2.13	10.74	17.00
2000	36.63	5.05	28.55	2.82	10.18	16.77
2001	36.74	5.08	28.24	2.79	10.21	16.95
2002	36.55	5.05	28.09	3.08	10.17	17.05
2003	36.38	5.03	27.96	3.16	10.45	17.02
2004	39.13	5.55	24.66	3.07	11.80	15.79
2005	37.61	9.64	23.04	2.96	11.51	15.25
2006	39.24	11.42	24.61	2.76	10.09	11.88
2007	39.65	11.39	24.15	3.08	10.13	11.59
2008	39.88	10.26	25.07	3.25	10.15	11.39
2009	39.23	10.73	25.74	3.58	9.50	11.22

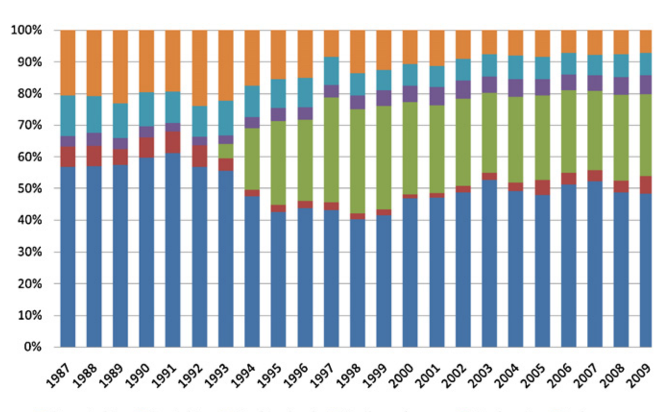

Fig. 5. Pattern of electricity generation for each type of power plants from 1987 to 2009.

while diesel engine power plants are slowly being phased out. From 1987 to 2009, the share of nominal capacity of electrical power generation of diesel engine power plants has shrunk from 22.82% to 9.50%. This is due to the introduction of combined cycle power plants that utilize both natural gas and diesel fuel. Additionally, the policy of using coal to generate electricity due to its low price had also contributed to the decrease of diesel engine power plant's share of power generation.

On the other hand, hydro-power plant's contribution for power generation has been steadily decreasing from 21% in 1987 to 11.2% in 2009. Furthermore, from time to time the share of electricity production from the hydro-power plants was less than its nominal capacity due to extreme weather that causes draught and limited water resources. Other than hydro-power, geothermal energy is another renewable resource that has been utilized by the country. Although this source contributes the lowest share of electrical energy supply, the geothermal energy saw a steady increase in nominal capacity and power generation contribution since 1987.

Table 11
Power plants electricity generation contribution (%) from 1990 to 2009.

Year	Steam turbine	Gas turbine	Combined cycle	Geothermal energy	Diesel engine	Hydro-power
1987	56.69	6.38	0.00	3.34	12.92	20.68
1988	57.01	6.34	0.00	4.06	11.63	20.96
1989	57.35	5.06	0.00	3.51	10.99	23.09
1990	59.53	6.57	0.00	3.40	10.90	19.61
1991	61.00	6.93	0.00	2.75	9.87	19.45
1992	56.82	6.67	0.00	2.69	9.87	23.94
1993	55.45	3.97	4.48	2.75	10.93	22.43
1994	47.32	2.22	19.36	3.51	10.09	17.50
1995	42.41	2.27	26.54	4.12	9.20	15.47
1996	43.77	2.23	25.54	4.02	9.30	15.15
1997	43.15	2.48	33.02	3.91	9.03	8.41
1998	40.22	1.84	32.92	4.33	7.03	13.66
1999	41.32	1.89	32.86	4.79	6.53	12.61
2000	46.78	1.34	29.02	5.22	6.91	10.73
2001	46.99	1.44	27.68	5.93	6.50	11.46
2002	48.66	2.06	27.47	5.76	6.87	9.18
2003	52.66	2.10	25.26	5.31	6.97	7.68
2004	49.17	2.65	27.17	5.54	7.43	8.05
2005	47.76	4.74	26.86	5.18	7.03	8.42
2006	51.14	3.78	25.93	5.00	6.92	7.23
2007	52.08	3.61	25.02	4.93	6.44	7.92
2008	48.56	3.76	27.21	5.56	7.19	7.71
2009	48.19	5.58	25.86	5.98	7.05	7.33

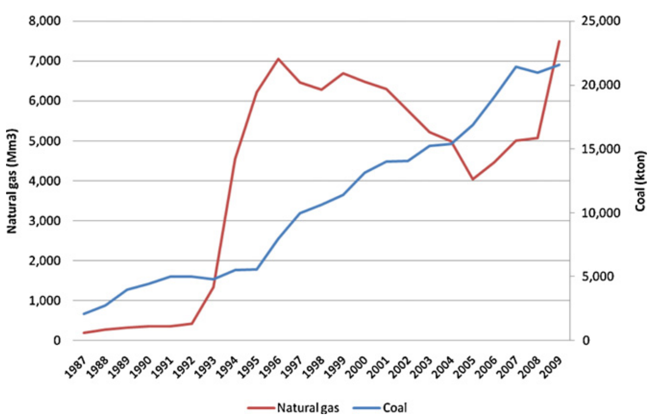

Fig. 6. Total fuel consumed for natural gas and coal in Indonesian power plants from 1987 to 2009.

4.4. Fuel consumption and emission production

Based in Tables 5 and 6, the total consumption of all types of fuel used in power plants in Indonesia is illustrated in Figs. 6 and 7 where the development of all types of fuel consumed by power plants is presented in the figure. The trend depicted in the figure shows that the country is still lagging in terms of utilizing natural gas as the primary fuel for power plants; while natural gas is expected to be the fastest growing fuel in the world [76]. Coal and diesel fuel are still being used for power plants in Indonesia due to their low operating costs and availability. Additionally, more than half of the natural gas reserves in Indonesia are exported to other countries. In response to increase domestic demands, Indonesia has established policies to prioritize domestic consumption of natural gas over exports [77]. Furthermore, the country had to make substantial investments to maintain current production levels due to declining natural gas production from many older fields. As a short-term solution, Indonesia's natural gas production has somewhat increased due to the new LNG export project which came into full production capacity in 2010 [78].

The average annual growth from 1987 to 2009 for natural gas was 18%, diesel 7.7%, fuel oil 1.2% and coal 11.2%. The total emission in Indonesian power plants was calculated using Eq. (8) and Tables 5–8. The total emission in Indonesian power plants from 1987 to 2009 is presented in Table 12 and illustrated in Fig. 8. For the past 23 years, the average annual growth rate of emissions from power plants was 7.6% for CO_2, 10.1% for NO_X, 4.4% for SO_2 and 6.4% for CO. As seen in Fig. 8, the increasing emissions of CO_2, SO_2 and NO_X were observed due to the increase in coal, diesel and natural gas consumption.

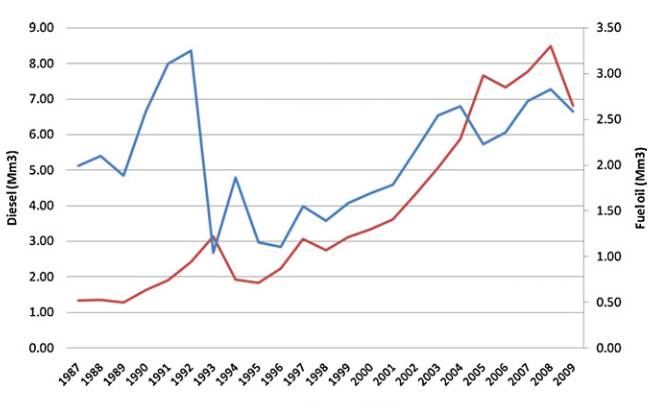

Fig. 7. Total fuel consumed for fuel oil and diesel in Indonesian power plants from 1987 to 2009.

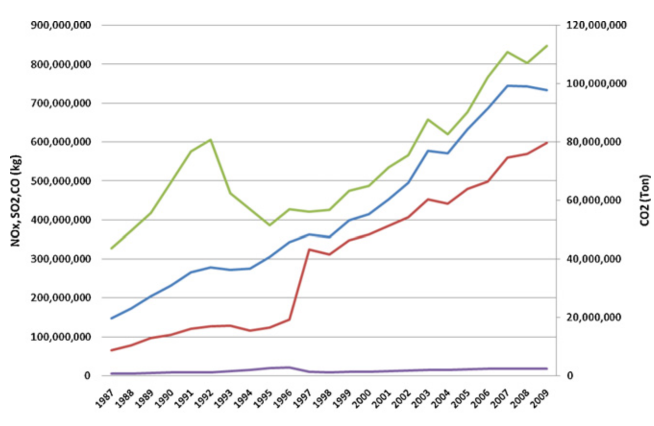

Fig. 8. Total emission in Indonesian power plants from 1987 to 2009.

Table 12
Total emission in Indonesian power plants from 1987 to 2009.

Year	CO_2 (ton)	NO_X (kg)	SO_2 (kg)	CO (kg)
1987	19,674,271	65,840,922	327,040,226	4,578,937
1988	23,005,347	78,478,481	371,045,699	5,385,631
1989	27,319,231	97,319,913	418,005,666	6,248,964
1990	30,806,773	106,075,480	495,322,458	7,075,598
1991	35,399,329	121,406,086	574,976,693	8,063,997
1992	37,242,724	127,027,948	606,195,538	8,576,391
1993	36,297,445	129,421,526	467,797,776	10,591,953
1994	36,746,057	116,139,275	427,185,656	14,628,081
1995	40,802,008	124,412,674	385,873,881	19,395,617
1996	45,703,063	145,404,677	427,445,615	20,761,833
1997	48,362,756	325,190,565	419,752,301	8,785,612
1998	47,534,919	312,321,805	425,297,166	8,585,081
1999	53,229,254	349,456,637	473,916,133	9,622,815
2000	55,281,571	363,228,572	487,668,076	10,011,830
2001	60,298,456	384,661,554	534,704,191	10,912,761
2002	66,051,720	407,180,603	566,489,410	12,030,448
2003	76,941,729	452,336,514	658,783,734	14,018,769
2004	76,098,362	442,496,138	619,956,676	14,004,790
2005	84,360,090	480,570,474	676,894,685	15,643,246
2006	91,524,338	498,815,280	766,716,883	16,818,474
2007	99,338,194	560,215,890	832,758,948	18,238,138
2008	99,156,959	570,072,214	803,997,587	18,325,461
2009	97,786,632	598,450,699	848,150,121	17,817,668

Table 13
Emission per unit of electricity generation from 1987 to 2009.

Year	CO_2 (ton/GWh)	NO_X (kg/Gwh)	SO_2 (kg/GWh)	CO (kg/GWh)
1987	933	3176	15773	200
1988	948	3305	15653	200
1989	982	3582	15397	200
1990	954	3348	15614	200
1991	949	3313	15647	200
1992	946	3288	15669	200
1993	1032	3987	15019	200
1994	996	3693	15285	200
1995	1036	4019	14975	200
1996	1066	4271	14744	200
1997	693	4235	6015	126
1998	626	3736	5605	113
1999	647	3873	5758	117
2000	592	3574	5225	107
2001	593	3500	5259	107
2002	610	3519	5234	111
2003	650	3619	5562	118
2004	633	3492	5159	117
2005	662	3627	5314	123
2006	688	3593	5760	126
2007	697	3770	5846	128
2008	663	3659	5380	123
2009	629	3627	5460	115

The emission per unit electricity generation is calculated using Eq. (10) and the results are tabulated in Table 13 and shown in Fig. 9. Observations can be made from Fig. 9 that the trend of emission per unit electricity generation decreased sharply in 1997. This is due to the global economic crisis that saw an increase in fuel prices which caused worldwide panic and predicament. Many factories and commercial buildings in Indonesia needed to shutdown their operations which result in decrease in electricity demand and hence result in low emission per unit electricity generation.

The share of each type of fuel in total thermal energy consumed and total emission in 2009 are calculated by using Eq. (7) and (9) and presented in Table 14. The year 2009 is taken as a sample to show the share of thermal energy contribution amongst the type of power plants by the highest fuel consumed and emission produced from 1987 up to 2009. For example, about 79.18% of thermal energy used in steam turbine power plants was contributed by coal, which produced more than 85% of the SO_2, CO_2, NO_X and CO gases due to the consumption of this type of fuel. The thermal energy of natural

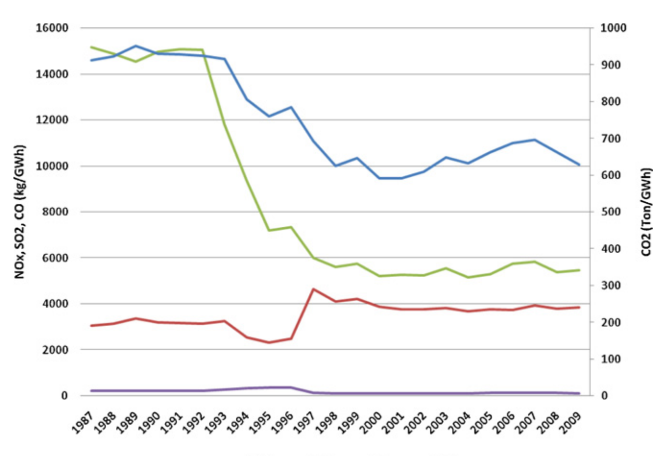

Fig. 9. Emission per unit electricity generation from 1987 to 2009.

Table 14
Fuel types contribution (%) in total emission and total energy consumed in power plants in 2009.

Fuel type	Pollutant	Steam turbine		Gas turbine		Combined cycle	
		Emission	Energy	Emission	Energy	Emission	Energy
Natural gas	CO_2	0.00		0.13		0.13	
	NO_X	0.00		38.81		58.56	99.94
	SO_2	0.00	1.7	15.63	99.94	15.34	
	CO	0.00		0.00		0.00	
Diesel	CO_2	–		99.87	0.06	99.87	0.06
	NO_X	–	–	61.90		41.44	
	SO_2	–		84.37		84.66	
	CO	–		100.00		100.00	
Fuel oil	CO_2	9.88		–		–	
	NO_X	4.40	19.12	–	–	–	–
	SO_2	0.17		–		–	
	CO	11.32		–		–	
Coal	CO_2	90.12		–		–	
	NO_X	95.60	79.18	–	–	–	–
	SO_2	99.83		–		–	
	CO	88.68		–		–	

Table 15
Total emission in thermal power plants from 2000 to 2009.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	CO_2 (ton)	46,441,734	1,253,637	2,846,318	4,739,882	55,281,571
	NO_X (kg)	196,892,637	7,169,767	30,209,302	128,956,866	363,228,572
	SO_2 (kg)	487,302,948	45,413	152,126	167,589	487,668,076
	CO (kg)	8,014,805	288,181	639,697	1,069,146	10,011,830
2001	CO_2 (ton)	50,714,850	1,447,757	3,320,320	4,815,529	60,298,456
	NO_X (kg)	214,694,358	8,536,147	30,416,086	131,014,962	384,661,554
	SO_2 (kg)	534,313,815	52,923	167,190	170,263	534,704,191
	CO (kg)	8,747,077	332,783	746,691	1,086,209	10,912,761
2002	CO_2 (ton)	54,533,997	1,908,729	4,574,781	5,034,214	66,051,720
	NO_X (kg)	227,029,701	11,387,676	31,798,550	136,964,676	407,180,603
	SO_2 (kg)	566,032,556	70,023	208,835	177,995	566,489,410
	CO (kg)	9,426,405	438,731	1,029,775	1,135,537	12,030,448
2003	CO_2 (ton)	63,489,888	2,369,700	5,829,242	5,252,899	76,941,729
	NO_X (kg)	262,001,914	14,239,200	33,181,009	142,914,391	452,336,514
	SO_2 (kg)	658,260,404	87,123	250,479	185,727	658,783,734
	CO (kg)	10,976,367	544,679	1,312,859	1,184,864	14,018,769
2004	CO_2 (ton)	60,486,319	2,202,634	8,114,202	5,295,207	76,098,362
	NO_X (kg)	248,049,347	14,213,381	36,167,950	144,065,459	442,496,138
	SO_2 (kg)	619,359,316	82,805	327,332	187,223	619,956,676
	CO (kg)	10,475,747	506,194	1,828,441	1,194,408	14,004,790
2005	CO_2 (ton)	64,060,998	4,568,634	10,229,663	5,500,796	84,360,090
	NO_X (kg)	266,342,273	27,904,691	36,664,648	149,658,862	480,570,474
	SO_2 (kg)	676,137,727	168,812	393,654	194,492	676,894,685
	CO (kg)	11,046,400	1,050,068	2,305,997	1,240,781	15,643,246
2006	CO_2 (ton)	72,085,235	4,131,782	10,391,990	4,915,331	91,524,338
	NO_X (kg)	300,749,159	26,171,693	38,164,168	133,730,261	498,815,280
	SO_2 (kg)	765,986,822	154,414	401,854	173,792	766,716,883
	CO (kg)	12,417,673	949,580	2,342,500	1,108,721	16,818,474
2007	CO_2 (ton)	78,714,545	4,131,713	10,392,576	6,099,360	99,338,194
	NO_X (kg)	328,752,437	25,986,008	39,533,572	165,943,873	560,215,890
	SO_2 (kg)	831,984,439	154,066	404,788	215,656	832,758,948
	CO (kg)	13,570,261	949,580	2,342,501	1,375,796	18,238,138
2008	CO_2 (ton)	76,640,752	4,451,470	11,376,989	6,687,747	99,156,959
	NO_X (kg)	317,109,742	27,848,015	43,162,481	181,951,977	570,072,214
	SO_2 (kg)	803,152,533	165,711	442,884	236,460	803,997,587
	CO (kg)	13,229,465	1,023,082	2,564,400	1,508,514	18,325,461
2009	CO_2 (ton)	79,686,425	2,914,991	7,857,960	7,327,256	97,786,632
	NO_X (kg)	332,296,303	26,721,731	40,081,723	199,350,941	598,450,699
	SO_2 (kg)	847,438,952	124,338	327,759	259,071	848,150,121
	CO (kg)	13,725,467	669,223	1,770,213	1,652,764	17,817,668

Table 16
Emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2009.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	CO_2	1,063,689.20	1,001,307.70	105,111.63	734,979.38	2,905,087.91
	NO_X	4509.58	5726.65	1115.60	19,996.41	31,348.24
	SO_2	11,161.06	36.27	5.62	25.99	11,228.94
	CO	183.57	230.18	23.62	165.78	603.15
2001	CO_2	1,061,713.11	992,294.22	117,997.08	728,742.21	2,900,746.63
	NO_X	4494.62	5850.68	1080.92	19,826.72	31,252.94
	SO_2	11,185.84	36.27	5.94	25.77	11,253.82
	CO	183.12	228.09	26.54	164.38	602.12
2002	CO_2	1,035,606.39	856,316.10	153,887.95	677,552.30	2,723,362.75
	NO_X	4311.32	5108.87	1069.65	18,434.01	28,923.85
	SO_2	10,749.02	31.41	7.02	23.96	10,811.41
	CO	179.01	196.83	34.64	152.83	563.31
2003	CO_2	1,017,955.56	953,217.99	194,827.61	635,944.16	2,801,945.31
	NO_X	4200.77	5727.76	1108.99	17,301.98	28,339.50
	SO_2	10,554.12	35.05	8.37	22.49	10,620.02
	CO	175.99	219.10	43.88	143.45	582.41
2004	CO_2	1,023,751.66	692,870.12	248,543.56	593,366.97	2,558,532.31
	NO_X	4198.32	4471.02	1107.85	16,143.60	25,920.79
	SO_2	10,482.87	26.05	10.03	20.98	10,539.92
	CO	177.31	159.23	56.01	133.84	526.38
2005	CO_2	1,053,080.57	756,521.66	299,016.78	613,996.60	2,722,615.61
	NO_X	4378.33	4620.75	1071.72	16,704.86	26,775.66
	SO_2	11,114.84	27.95	11.51	21.71	11,176.01
	CO	181.59	173.88	67.41	138.50	561.37
2006	CO_2	1,059,049.09	821,264.66	301,033.86	533,752.95	2,715,100.55
	NO_X	4418.49	5202.09	1105.53	14,521.69	25,247.81
	SO_2	11,253.59	30.69	11.64	18.87	11,314.79
	CO	182.44	188.75	67.86	120.40	559.43
2007	CO_2	1,061,071.73	802,586.04	291,647.75	665,433.15	2,820,738.67
	NO_X	4431.58	5047.79	1109.43	18,104.28	28,693.09
	SO_2	11,215.15	29.93	11.36	23.53	11,279.96
	CO	182.93	184.46	65.74	150.10	583.22
2008	CO_2	1,056,094.15	791,935.58	279,787.26	622,347.58	2,750,164.57
	NO_X	4369.71	4954.28	1061.47	16,932.07	27,317.52
	SO_2	11,067.28	29.48	10.89	22.00	11,129.66
	CO	182.30	182.01	63.06	140.38	567.75
2009	CO_2	1,064,458.46	336,060.81	195,641.98	668,667.26	2,264,828.51
	NO_X	4438.84	3080.67	997.93	18,192.27	26,709.71
	SO_2	11,320.17	14.33	8.16	23.64	11,366.30
	CO	183.35	77.15	44.07	150.83	455.40

gas is very small in comparison to coal as they are used in small percentage in steam turbine power plants. The emissions of burning natural gas, however, are lower than that of coal. Thus, if the solid fuel of coal is replaced by natural gas, a significant amount these greenhouse gas emissions may be reduced. Furthermore, diesel fuel used in gas turbine and combined cycle power plants contributed the highest amount of emissions although the thermal energy from this type of fuel is lower than that of natural gas as can be seen in Table 14.

Between 1987 and 2009, there was detailed information of fuel consumed and electricity generated for all types of power plants. Thus, the amount of total emission and emission per unit of electricity generation in each type of power plants were more precisely determined. These data are calculated using Eqs. (8) and (11) and presented in Tables 15 and 16.

The emission per unit electricity generation for each type of power plants in Indonesia was calculated by Eq. (12) using the data in Table 15 and the results are tabulated in Table 16. The data of this table has been calculated using ten years of fuel mix data. Thus, by changing the fuel mix used in thermal power plants, this data will be affected. For example, by increasing the contribution of natural gas in power plants, the emission per unit electricity generation will decrease. The average emission per unit electricity generation in between 2000-2009 provided in (Table 17).

The data for year 2009 in Table 16 is selected to show the share of each type of power plant for total emissions. The contributions of each type of thermal power plants in total emission in 2009 are presented in Fig. 10. The figure shows that the contribution of steam turbines for all types of emission was very significant, particularly for SO_2 emission. Although diesel engines are slowly being phased out, their emission contribution is somewhat significant, mostly

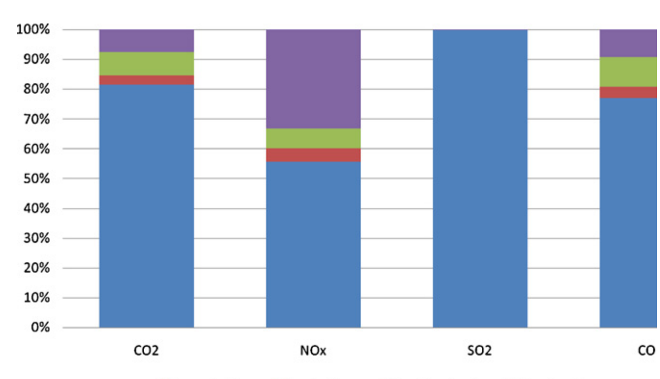

Fig. 10. Power plant emission contribution in 2009.

Table 17
Average emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2009.

Emission	Steam turbine	Gas turbine	Combine cycle	Diesel engine
CO_2	1,049,647	800,437	218,750	647,478
NO_X	4375	4979	1083	17,616
SO_2	11,010	30	9	23
CO	181	184	49	146

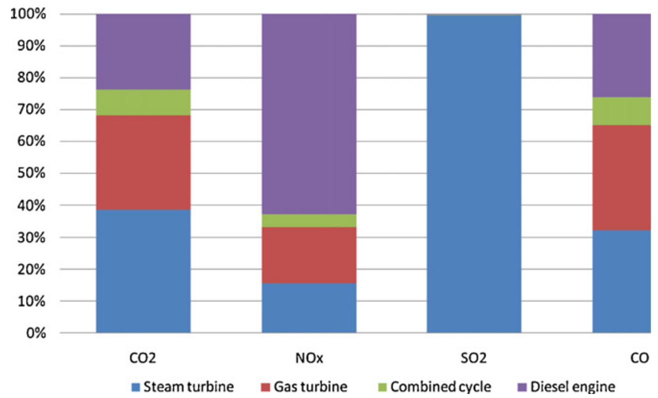

Fig. 11. Comparison between thermal power plants with regard to emission.

due to inefficient and old diesel engines are still being used in the power plants.

Fig. 11 shows the comparison of each type of emission in all thermal power plants in Indonesia. By comparing the thermal power plants with regards to the emissions produced, the worst type of power plant is steam turbine that produced the highest amount of emissions while the best type is the combined cycle. Note that the amounts of emissions produced by diesel engine power plants are quite high although they are slowly being phased out in Indonesia. Thus by removing the inefficient diesel engine power plants off the grid cleaner energy production can be achieved in the long run.

5. Conclusion

This study describes an investigation of electricity generation pattern and emission in Indonesia for the past 23 years since 1987–2009. The study shows that Indonesian electricity sector still highly depends on fossil fuel resources especially diesel oil and coal as primary energy sources and these are also the major contributor of greenhouse gas emissions in the country. Non-renewable energy consumption such as fossil fuel for electricity generation has increased to fulfill energy demand in the country. Furthermore, the increase of fuel consumption will give rise to the level of emissions that are dangerous to human health. The data from this study shows that the best type of thermal power plant with regards to air pollution is the combined cycle power plant whereas the worst type of power plant is the steam turbine. As shown in the study, most of gas emissions came from coal that is used in steam turbine. Moreover, Indonesian government plan to construct coal fired power plant in the near future due to the abundance of coal reserves in Indonesia. In order to decrease emission production from thermal power plant, the government should apply clean coal technology. On the other hand, by replacing fuels that produce high level of emissions such as coal, fuel oil and diesel with natural gas, greenhouse gas emissions can be reduced significantly as natural gas produces low emission into the air. Therefore, based on the data presented in the study, construction of new combined cycle power plants in the near future may solve electricity shortages in the country while maintaining cleaner production of energy.

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